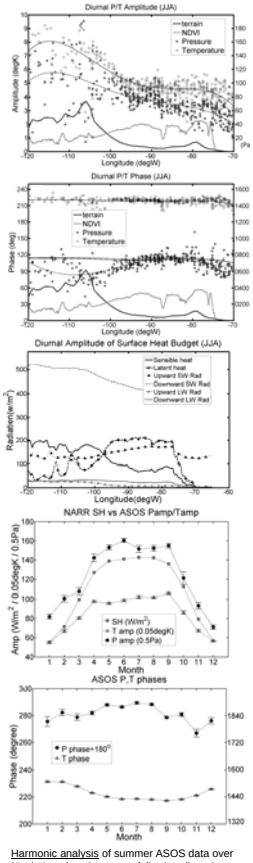
Observation and theory of the diurnal continental thermal tide

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1.Introduction Diurnal pressure disturbances found over the continents are mainly caused by diurnal PBL heating, the so-called thermal continental tide. In this work, we construct a simpler "local" tidal theory that applies to an isolated continent with inhomogeneous sun-following heating, neglecting the rest of the globe and spherical effects.

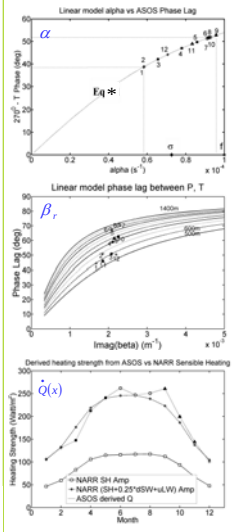
2. Observations

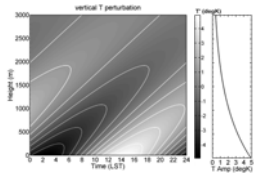


Harmonic analysis of summer ASOS data over North America shows sun-following diurnal temperature and pressure oscillations with amplitudes increasing in the western USA, i.e. 5 to 8 degC and 60 to 120 hPa respectively, due to larger sensible heating in the dryer western terrains. The phases of temperature and pressure (i.e. 220° and 110°) are constant with longitude after an interfering eastward propagating wave is removed. Tidal amplitudes and phases shift significantly with season.

3. A linear theory of the continental enhanced tide

Linearized Boussinesq equations is applied to study the thermal tide excitation due to heating from the ground.





$$u_t + Uu_x + Vu_y - fv = -p_x - \alpha u$$
$$v_t + Uv_x + Vv_y + fu = -p_y - \alpha v$$
$$w_t + Uw_x + Vw_y = -p_z + b - \alpha w$$
$$b_t + Ub_x + Vb_y + N^2 w = B - \alpha b$$

with $\dot{Q}_s(x,z,t) = \frac{\rho_0 C_p T_0}{g} B_0 B_h(x) e^{-\beta z} e^{i\sigma(t+\frac{x}{C_s})}$

Analytical solutions in Fourier space considering long-wave limit

$$\hat{p}(k,z) = \frac{iB_0\hat{B}_h(k)\cdot e^{i\sigma\frac{x}{C_s}}}{\bar{\sigma}\beta} e^{-\beta z}$$

$$\hat{T}(k,z) = \frac{T_0}{g}\frac{B_0\hat{B}_h(k)\cdot e^{i\sigma\frac{x}{C_s}}}{i\bar{\sigma}} e^{-\beta z}$$

with $\bar{\sigma} = \sigma - i\alpha$

$$m^2 = N^2\left(k + \frac{\sigma}{C_s}\right)^2 \Big/ \left(f^2 - \bar{\sigma}^2\right) << \beta^2$$

$$T'(x,z=0,t) = \mathrm{Re}\left[\frac{T_0 B_0 B_h(x)}{g(i\sigma+\alpha)}\cdot e^{i\sigma\left(t+\frac{x}{C_s}\right)}\right] \Rightarrow \Delta T_{phs} = \tan^{-1}\left(\frac{\sigma}{\alpha}\right) *$$

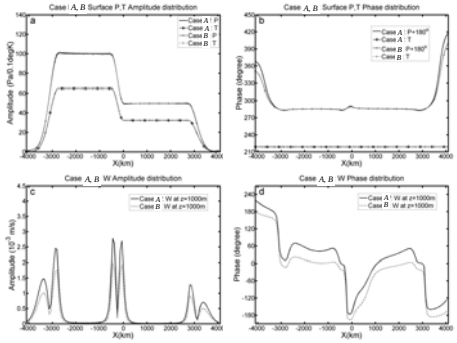
$$\frac{\hat{p}(k,z)}{\hat{T}(k,z)} = -\frac{g}{T_0}\frac{(\beta_r - i\beta_i)}{(\beta_r^2+\beta_i^2)} \Rightarrow \begin{cases} \Delta\psi_{P,T} = \psi_p + 180^o - \psi_T = \tan^{-1}\left(\frac{\beta_i}{\beta_r}\right) \\ R = \frac{P_{Amp}}{T_{Amp}} = \frac{g}{T_0}\frac{1}{\sqrt{\beta_r^2+\beta_i^2}} \end{cases}$$

$$T_{Amp}(x,z=0) = \frac{T_0}{g}\cdot\frac{B_0 B_h(x)}{\sqrt{\sigma^2+\alpha^2}} \Rightarrow \dot{Q}(x) = \rho C_p \frac{\sqrt{\sigma^2+\alpha^2}}{\sqrt{\beta_r^2+\beta_i^2}}\cdot T_{Amp}(x,z=0)$$

4. Linear model simulations

Linear model set up for Case *A, B*:
Heating: exponentially decay, sun-following, doubled heating rate in the western part of the continent,
$\beta_r^{-1} = 1200$ m.
$\beta_i^{-1} = 500$ m,
$\alpha = 9\times10^{-5}\ s^{-1}$
Coriolis effect: Case A, f=0; Case B, f=10^{-4}.

When the model is applied to an inhomogeneous continent, we obtain a clearer idea of how wide a region needs to be to approach the tidal (i.e. long wave) limit. Traveling diurnal heating generates gentle tides over the large uniform interior regions but causes vigorous sea breezes and mountain-plain circulations in regions of heating gradient. These gradient regions have significant vertical motions and are moderately sensitive to the Coriolis force and the mean wind speed. Surprisingly, these local circulations do not alter the phases of the temperature and pressure oscillations, in agreement with observations.



5. Conclusion

A theory of the continental tide is developed from the linearized Boussinesq equations including an important damping term and a vertical heating profile with decay and delay. The phase and amplitude of the diurnal component of the surface temperature are controlled by a hypothesized damping. The stronger the damping, the less will be the phase lag between surface temperature maximum and the peak time of ground heating (local noon). The phase lag between surface pressure and temperature is caused by the time delay during vertical turbulent heat transport. The complex ratio of pressure and temperature amplitudes can be used to determine the heating profile exponent and the turbulent heat transport coefficient.

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